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Trade, Education, Governance and Distance: Impact on Technology Diffusion and Productivity Growth in Asia and LAC*

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Abstract

This paper examines the impact of North-South trade, education, governance and North-South distance, on technology diffusion and total factor productivity (TFP) growth in the South, focusing on LAC and East Asia over the 32 years before the Great Recession (1976-2007). Findings are: i) TFP rises with education, trade, governance (ETG) and imports' R&D content, and falls with distance to the North; ii) an increase of LAC's ETG to East Asia's levels raises TFP by 165%, fully accounting for its TFP gap with East Asia; iii) the impact of the education gap equals the sum of the governance and openness gaps; and iv) South America's loss of TFP relative to Mexico associated with its greater distance to US-Canada (both Europe and Japan) is 9.3 (0) percent.

JEL: F22, J61
Keywords: Trade, Governance, Education, Distance, Technology Diffusion, Productivity growth.

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Introduction

High and sustainable levels of economic growth are unlikely to prevail in the absence of significant and persistent productivity growth. In its absence, a high investment rate may generate high growth rates for a period of time but it must eventually run into diminishing returns. This paper looks at productivity growth and to how it was affected by North-South technology diffusion, education and governance over the three decades before the Great Recession. It compares two regions, East Asia (defined here as Hong Kong, Singapore, South Korea and Taiwan) and LAC (Latin America and the Caribbean). As is well known, East Asia's economic growth took off in the 1960s, with annual growth for 1960-2008 averaging around 6 percent in Taiwan, 5.5 percent in South Korea and 5 percent in Hong Kong and Singapore. East Asia's per capita income relative to that of the US increased from around 15 percent in 1960 to over 70 percent in 2010, while that of LAC has remained at around 30 percent. In fact, per capita income in LAC, which was double that of East Asia in the 1960s, fell to about 36 percent of East Asia's income by 2010 (World Bank 2011, pp. 22-23), a relative decline of some 80 percent.

A large number of studies have examined economic growth in East Asia and in LAC. Jaspersen (1997) focused on education, inequality,[1] savings, trade, macro policy and capital markets as the main determinants of economic growth and of the regions' differential growth rates. Ito and Krueger (1995) examined the determinants of East Asia's success, including trade and trade policy, government spending, investment in education, and accumulation of knowledge (new ideas, production techniques, etc.). The latter was also emphasized in Drysdale and Huang (1997) who showed that productivity growth was a key element of East Asia's economic growth.

This study focuses on total factor productivity (TFP) growth and on differences between East Asia and LAC. Various determinants of economic growth in the studies discussed above also play a crucial role for TFP growth, including trade, education, and technological knowledge. Specifically, we examine the impact on TFP of educational attainment, North-South trade-related technology diffusion, governance, and distance.

[1] Other studies on inequality and growth in East Asia include Birdsall et al. (1995), which shows that greater equality had a positive impact on East Asia's economic growth, and You (1989) who finds that low inequality of both income and wealth contributed significantly to South Korea and Taiwan's rapid growth. These results seem particularly important for LAC, the developing region with the highest level of inequality.

An influential paper by Alwyn Young (1995) examined economic growth in East Asia and the OECD and argued that the difference between East Asia's and the OECD's growth rate was essentially due to higher savings rates and capital accumulation, not to higher productivity growth. This view has been challenged by other studies. One argument is that TFP growth generates further investments. Thus, the 'residual' understates TFP's full impact on growth. For instance, Hulten (1975) estimated TFP's impact on US growth in 1948-1966 to be 90 percent above the conventional measure (65 percent instead of 34 percent).

Another argument that has not been addressed in the literature is that East Asia's rapid growth occurred in a period of low global productivity growth rather than during a high OECD and global growth period, and correcting for the global growth difference results in a substantially higher rate of TFP growth in East Asia than in the OECD. Annual productivity growth slowed down significantly following the 1973 oil crisis (Denison 1985). The OECD's high growth took place in the pre-1973 period while East Asia's high growth continued in the low-growth post-1973 period as well. Young's (1995) sample period for the OECD countries is entirely in the high-growth, pre-1973, period, while about three quarters of the East Asia observations (1966-90 sample period) are in the low-growth period. Comparing East Asia and OECD's growth rates over the same period shows that TFP growth explains a substantially larger share of the growth differential between the two regions.

Other studies have found that productivity differences across countries play an important role in explaining their economic performance. Cole et al. (2005) find that TFP rather than human capital has been the dominant force behind Latin America's economic performance, and Kydland and Zarazaga (2002) conclude that Argentina's poor economic performance in the 'lost decade' of the 1980s was due in large part to the decline in its TFP. As for the importance of TFP for economic growth in a developed country, Prescott and Hayashi (2002) show that the low rate of growth of TFP explains Japan's poor economic performance since the early 1990s.

Given TFP's contribution to economic growth, this paper estimates the TFP impact of various determinants, namely two alternative measures of technology diffusion (and discusses the estimation with a third measure in Sections 2 and 6), education, trade, governance and distance, and examines the extent to which differences in the level of these determinants explain the gap in TFP growth between LAC and East Asia.

One hypothesis is that East Asia benefitted from trade with and FDI from Japan through absorption of technological knowledge, resulting in higher growth rates. Japan was one of East Asia's major trading partners in the 1960s and 1970s, and outsourcing some of its production to them resulted in increased knowledge transfer through their imports of R&D-intensive goods and through activities associated with production processes and quality control, leading to further knowledge diffusion over time to other Asian countries, especially in South-East Asia (World Bank, 2011).

On the other hand, productivity growth in the last fifty years has been much lower in LAC than in East Asia, suggesting that technology diffusion from the US and Canada to LAC has been weak compared to that from Japan to East Asia. As shown in Table 1, East Asia's log TFP in 1976-2007 was 36 percent higher (43 percent higher for TFP, not shown) than in MCC (Mexico, Central America and Caribbean),[2] 40 (49) percent higher than in Mexico, 46 (58) percent higher than in LAC as a whole, 56 (75) percent higher than in South America,[3] and 63 (88) percent higher than in South-East Asia.

Until the late 1980s, growth analysis was based on the neo-classical growth model, resulting in disappointingly small gains from trade. Endogenous growth theory (Romer 1986, Lucas 1988) enabled policy to move the economy to a higher growth path, thus generating larger gains from policy reform. While endogenous growth in the Lucas (1988) model is associated with human capital externalities, Romer (1990), Grossman and Helpman (1991a) and Aghion and Howitt (1992) emphasize the role of knowledge (R&D). Grossman and Helpman (1991b) expanded the model to the open economy: since goods embody technological know-how, countries can acquire foreign knowledge and raise productivity growth through trade liberalization. Coe and Helpman (1995) provided an empirical implementation of Grossman and Helpman's (1991b)

[2] The MCC region consists of Mexico, El Salvador, Panama, and Trinidad and Tobago, countries for which data on industry-level capital stocks are available. These are needed to calculate industry-level TFP.
[3] South America consists here of Bolivia, Chile, Colombia, Ecuador, Peru, Uruguay and Venezuela, for which data on industry-level capital stock are available.

model, emphasizing the role of openness as well as education. Their approach constitutes the first of the two approaches used in the empirical analysis.

The importance of institutions for economic growth has been the subject of a vast literature, including Davis and North 1971; North 1990; Barro 1996; Sokoloff and Engerman 2000; and Acemoglu et al. 2001, 2002, to cite a few. Numerous studies have examined specific aspects of institutional quality, including rent seeking (e.g., Krueger 1974), corruption (e.g., Mauro 2002), etc. It is hypothesized here that the importance of institutions for economic growth extends also to productivity growth, and a 'governance' variable is included in the empirical analysis.

The paper is organized as follows. Section 2 presents the empirical framework, including a new measure of education. Section 3 describes the data and Section 4 discusses some initial findings derived from it. Section 5 provides the empirical results and Section 6 briefly describes a robustness test, as well as a 'nesting' test in order to determine whether a specification that includes distance between source and recipient countries is preferred to one that does not. Section 7 performs a number of simulations where we examine the impact on TFP in LAC (and in some LAC countries and regions) when explanatory variables take values from East Asia (and from specific Asian countries and regions). Section 8 provides a brief discussion on education policy in LAC and Section 9 concludes.

2. Empirical Implementation

This section describes Coe and Helpman's (1995) empirical implementation of Grossman and Helpman's (1991b), which constitutes our first approach. An alternative model of technology diffusion was set out by Keller (2002) that incorporates the impact of distance but abstracts from trade. He found that knowledge's impact on productivity declines with the distance between the technology source and recipient countries. This paper develops, as a second approach, an empirical model that consists of a combination of Coe and Helpman's (1995) and Keller's (2002) specifications of the technology diffusion process. This enables us to examine the impact of both trade and distance on North-South technology diffusion and TFP growth in the South. We also provide a test to determine which of the two models is the preferred one.

The focus is on manufacturing industries where the bulk of North-South technological diffusion takes place.[4]

Coe and Helpman (1995) construct an index of 'foreign R&D', defined as the trade-weighted sum of trading partners' R&D stocks, and find for developed OECD countries that both domestic and foreign R&D stocks have a large and significant impact on TFP, so that TFP increases with the economy's openness. Other studies have obtained similar results.[5]

2.1. Measures of "foreign R&D" and estimation equation

We use industry-level versions of two country-level measures of 'foreign R&D.' These are i) Coe and Helpman (1995), and ii) a combination of Coe and Helpman (1995) and Keller (2002). The North consists of the G7 countries where most of the R&D is generated. The R&D in other developed countries, which is relatively small, is absorbed in large part by the G7 countries through direct and indirect trade-related technology diffusion (Lumenga-Neso et al., 2005).

The two measures of foreign R&D are as follows.

Model 1: Linear Trade-Weighted R&D

The industries in our analysis are aggregated into two groups of interest: R&D-intensive industries and low-R&D industries. We define the variable "North-foreign R&D" of industry j of developing country c, NRD_{cj} as:

$$NRD_{cj}^{T} = \sum_{k} \frac{M_{cjk}}{VA_{cj}} RD_{kj} , \qquad (1)$$

where c indexes developing countries, k indexes the G7 countries, and j indexes industries, VA_{cj} is the value added of country-industry cj, M_{cjk} is the value of imports of country c from G7

[4] Empirical analysis of FDI's impact on productivity requires bilateral industry-level FDI data but bilateral North-South FDI data at the industry level are not available; industry-level data only exist for the OECD as a whole (as the source region). Given that i) studies of trade and FDI's productivity impact in this literature typically find the former's impact to be substantially greater than the latter (with FDI also typically either weakly or not significant statistically), and ii) the abundance of bilateral trade data and the lack of bilateral North-South industry-level FDI data, the analysis focuses on trade-related technology diffusion and its impact on productivity.

[5] Coe et al. (1997) examine the impact of North-South trade-related technology diffusion on TFP in the South and obtain similar results. Other studies have tended to confirm Coe and Helpman's (1995) findings. These include country-level analyses by Engelbrecht (1997), Falvey et al. (2002), Lumenga-Neso et al. (2005), and Coe et al. (2008) who extend Coe and Helpman's (1995) econometric analysis, and industry-level analyses by Schiff and Wang (2006, 2008) who examine both North-South and South-South technology diffusion.

country k for industry j, RD_{kj} denotes industry-j's R&D stock in G7 country k, and time subscripts are excluded for the sake of clarity. Equation (1) says that, for any country-industry cj, NRD is the sum, over all G7 countries k, of the R&D stock of country-industry kj, weighted by country c's ratio of industry j's imports from country k divided by industry j's value added in country c. This measure abstracts from the impact of distance on TFP.

Model 2: Non-Linear Distance-Corrected R&D

Keller (2002) specified a foreign R&D index of international technology diffusion that includes distance between the technology source and recipient countries but excludes trade. The measure of NRD he used is

$$NRD_{cjt} = \sum_k e^{-\delta * Distance_{ck}} * RD_{kjt} \ , \tag{1'}$$

with a positive δ indicating that the impact of foreign technology on recipient countries' TFP declines with distance.

Model 3: Non-Linear Trade-Weighted Distance-Corrected R&D

We specify a model that includes both distance and trade, namely:

$$NRD_{cjt}^{DT} = \sum_k e^{-\delta * Distance_{ck}} * \left(\frac{M_{cjkt}}{VA_{cjt}} \right) * RD_{kjt}. \tag{2}$$

Equation (2) says that an industry's foreign R&D in a given country rises with its trading partners' R&D stocks and imports of a given industry's products relative to that industry's value added, and – assuming $\delta > 0$ – declines with distance from its trading partners.[6]

The benchmark estimation equation is:

$$\log TFP_{cjt} = \alpha + \beta \log NRD_{cjt} + \beta^{Edu} Edu_{ct} + \beta^{Gov} Governance_{ct} + \sum_{c=2} \gamma_c D_c + \sum_{t=2} \gamma_t D_t + \varepsilon_{cjt} \ , \tag{3}$$

[6] The negative impact of distance on NRD and TFP was obtained in Schiff and Wang (2003, 2009) who find that productivity growth comes mainly from proximate developed trading partners, e.g., we found that trade with 'US + Canada' had a strong impact on Mexico's TFP but trade with EU-15 and Japan did not. The latter had the greatest impact on South Korea's TFP growth, suggesting that proximity raises trade's productivity impact. The number of countries in our sample, though, was small and is greatly expanded here.

where γ_c (γ_t) is a country (time) fixed effect; NRD_{cjt} is the foreign R&D variable which is defined in equations (1), (1') and (2) above, *Edu* is the country's educational attainment measured as the secondary school completion ratio of the population 15+, adjusted for quality, *Governance* is a governance index, ε is an error term, and subscript *c* (*t*) (*j*) denotes country (year) (industry). The governance index, from Kaufmann et al. (2010), is an average of six indicators (based on a large number of more disaggregated indicators), ranging from – 2.5 to 2.5.

The theory underlying equation (3) is presented in Grossman and Helpman (1991b) and Helpman (1992), and a non-technical explanation is found in Section 2 in Coe and Helpman (1995).[7] Due to lack of data, and following other studies in this literature, developing countries' domestic R&D stocks are excluded. This should not constitute a major problem given that most of the world's R&D is still performed in developed countries.[8] We also added a related measure in our regressions, namely the annual number of patent applications by the developing countries, but it was not significant and had a negligible impact on the results.

2.2. Education and R&D intensity

The measure of education used is is the secondary school completion ratio for the population aged 15 and above, from Barro and Lee (2004), annualized using a constant growth rate. Developing countries' capacity to absorb technology from the North and use it productively is closely related to the education of the labor force (e.g., Correa et al. 2008).[9]

Following Schiff and Wang (2006, 2008), the manufacturing sector is divided into the R&D-intensive and low R&D-intensive industries (or low-R&D industries). R&D intensity is measured here as the ratio of an industry's investment in R&D over its value added in the US.

[7] Grossman and Helpman (1991b) develop two alternative models, with intermediate inputs differentiated either horizontally or vertically. Both imply that TFP increases with a country's average R&D stock.

[8] For instance, 94 percent of the world's R&D expenditures took place in industrial countries in 2005 (authors' calculations based on World Bank database). Moreover, empirical work has shown that a major part of the technical change in individual developed OECD countries is based on the international diffusion of technology among the various developed OECD countries. Eaton and Kortum (1999) estimate that 87% of French TFP growth is based on the diffusion of R&D from other developed OECD countries, and Lumenga-Neso et al. (2005) show the importance of these 'indirect' effects for developed countries in general. Since developing countries invest much fewer resources in R&D than developed OECD, foreign R&D must be even more important for the former as a source of growth than for developed ones.

[9] As discussed below in Section 3, Argentina and Brazil are excluded due to a lack of data on industry-level capital stock.

Using data on US manufacturing at the 2- and 3-digit level of ISIC revision 2, we have six (ten) industries in the R&D-intensive (low-R&D) group, and these are collected into two aggregate industry groups.[10]

2.3. Econometric issues

Studies in this literature have estimated equation (4) by OLS, though potential reverse causality suggests estimation by instrumental variables (IV) might be warranted. Tests for the instruments' validity under IV estimation can be used in the case of stand-alone variables in linear regressions. However, NRD in equation (1) consists of the ratio of *a*) the sum of each G7 country's R&D stock multiplied by the importing country's bilateral imports from the respective G7 country, and *b*) the importing country's value added in the respective industry, and equation (2) also includes a non-linear distance term. Thus, validity of the instruments cannot be established under such conditions. Moreover, goodness of fit did not improve when using IV estimation, and it had little impact on the NRD coefficient.

An exception to the OLS estimation is Coe et al. (2008) who use panel co-integration estimation. They argue that an advantage of this approach is that parameter estimates are 'super' consistent (robust to issues of endogeneity, simultaneity, omitted variables). They use two panel co-integration estimation methods and generally obtain similar results to the OLS estimation in their original paper (Coe and Helpman, 1995). Based on these considerations, the equations are estimated by OLS. Finally, since equation (1) [(1')] is nested in equation (2), we can perform an F-test for the significance of the additional variable, namely distance [trade], and whether including it improves the estimation of the TFP relationship in a statistically significant way.

3. Data Description

The data cover 32 developing countries and 7 industrialized OECD trading partners (the G7 countries) over the period 1976 – 2007, the period up to but excluding the Great Recession. The

[10]The 6 industries in the R&D-intensive industry group are (at the ISIC revision 2 classification): 353/354 - Petroleum Refineries and Products, 355/356 – Rubber and Plastic Products, 382 – Non-Electrical Machinery, Office and Computing Machinery, 383 – Electrical Machinery & Communication Equipment, 384 – Transportation Equipment, and 385 – Professional Goods. The 10 industries in the low-R&D group are: 31 – Food, Beverage and Tobacco, 32 – Textiles, Apparel and Leather, 33 – Wood Products & Furniture, 34 – Paper, Paper Products & Printing, 351/352 – Chemical, Drugs and Medicines, 36 – Non-Metallic Mineral Products, 371 – Iron & Steel, 372 – Non-Ferrous Metals, 381 – Metal Products, and 39 – Other Manufacturing.

32 developing countries are collected into five groups: 1) Hong Kong (China), Singapore and South Korea in East Asia;[11] 2) Indonesia, Malaysia and the Philippines in South-East Asia; 3) Bolivia, Chile, Colombia, Ecuador, Peru, Uruguay and Venezuela in South America[12]; 4) Mexico, El Salvador, Panama, and Trinidad and Tobago in the 'Mexico, Central America and Caribbean' (MCC) region; and 5) the group of fourteen "Other Countries": Bangladesh, India, Nepal, Pakistan and Sri Lanka in South Asia; Cameroon, Kenya and Malawi in Sub-Saharan Africa; Morocco and Tunisia in North Africa; and Egypt, Jordan, Kuwait and Turkey in the Middle and Near East. The G7 countries are the United States, Canada, Japan, and the EU's four largest economies: France, Germany, Italy and the United Kingdom.

The log *TFP* index is the difference between the logs of value-added and primary factor use, with the inputs weighted by their income shares, i.e., $\ln TFP = \ln Y - \alpha \ln L - (1-\alpha).\ln K$, where α is the mean labor share over the sample period. The labor share is the ratio of the wage bill over value added. Fixed capital formation used to construct capital stocks, value added, labor and wages, is from the World Bank database (Nicita and Olarreaga 2007), with all reported in current US dollars at the 3-digit ISIC codes (Revision 2).

Value added and fixed capital formation are deflated by the US GDP deflator (1991=100), and capital stocks are derived from the deflated fixed capital formation series using the perpetual inventory method with a 5% depreciation rate.[13] R&D expenditure for the G7 countries is taken from OECD ANBERD with ISIC Revision 2 (2002) covering data from 1973 to 1998 and ANBERD with ISIC Revision 3 (2006) covering data from 1987 onward. Since ANBERD ISIC 2 and ISIC 3 have 12 years of overlapping data, we are able to match the different specifications. The R&D stock in each country is constructed from R&D expenditures using the perpetual inventory method with a 10% depreciation rate.

Bilateral trade data of the 32 developing countries with the G7 industrialized OECD countries at the 4-digit ISIC 2 level are from World Bank data (a description is in Nicita and Olarreaga

[11] Taiwan is excluded due to lack of data (it is not a member of international organizations that collect the relevant data).
[12] Argentina and Brazil are excluded due to lack of data on industry-level fixed capital formation.
[13] Given that the data reported in Nicita and Olarreaga (2007) are in current US dollars, we use the US GDP deflator. In the empirical analysis, country-specific as well as year dummies are used to control for potential distortions introduced by the conversion.

2007). We construct bilateral trade shares for each year, each composite industry and for each of the 32 developing countries with respect to each of the G7 OECD countries, and these are then used to construct the various *NRD* measures, as defined in equations (1) and (2).

Secondary school completion ratio for population aged 15+ and above is obtained by annualizing the five-year averages in Barro and Lee (2010). We matched the few countries not included in Barro and Lee's dataset with those included, using indicators such as real GDP per capita, government expenditure on education as a share of GDP, and more.

Institutions and their role in the process of economic development have been intensively studied in recent years. The present study contributes to this literature by examining the impact of governance on TFP in a technology diffusion framework. The governance index is from Kaufmann et al. (2010). It consists of an average of six governance indicators and ranges between – 2.5 and 2.5.[14] As Section 5 shows, governance is found to significantly affect TFP, a result obtained by Schiff and Wang (2011) in the case of LAC. Finally, distance is defined as the shortest distance between countries' capitals and is measured in thousands of kilometers.

Due to missing observations, our sample is unbalanced. It has 64 panels (32 countries, each with a composite R&D-intensive and composite low-R&D industry), with 1750 observations.

4. Initial look at the data: What do they say?

Tables 1 to 3 provide data on the level and growth of TFP, governance, education, R&D stocks, NRD and per capita GDP. Trade flows are also discussed. Data for groups of countries/regions are weighted averages.

4.1. Trade Flows

Matrices of bilateral imports shares for 1990-2007 between each G7 country and eleven LAC and twelve Asian countries were collected in various tables which, for the sake of brevity, are not presented here but are available from the authors. For the entire period, Japan and the US

[14] The six indicators in Kaufmann et al. (2010) are: Control of Corruption, Rule of Law, Political Stability, Absence of Violence/Terrorism, Government Effectiveness, and Regulatory Quality. They are based on 30 underlying data sources reporting the perceptions of governance of a large number of survey respondents and expert assessments worldwide. We estimated a regression of Governance on a number of variables and extrapolated back to the earlier years for which data are not available.

are the main G7 trading partners of LAC and developing East Asia, with the US (Japan) providing some 38% (5.5%) of LAC's total imports and 15% (22%) of East Asia's total imports, and with larger shares for R&D-intensive imports: 43.5% (9.5%) for LAC and 17.5% (28%) for East Asia.

As one might expect, a developing country only imports a small share of any G7 country's exports. A major exception in LAC is Mexico, whose imports from the US account for close to 12% of US manufacturing exports. In East Asia, South Korea is, at 8.3%, the major destination of Japan's exports, with the average for Hong Kong and Singapore amounting to 5.2%.

4.2. TFP, Governance and Education

Table 1 shows log TFP, governance and education for the four regions of interest for 1976 – 2007. TFP is highest for East Asia. Its log TFP is 2.93 or 36% above MCC's 2.15, 40% above Mexico's 2.10, 56% above South America's 1.88, and 63% above South-East Asia's 1.80. Note that East Asia's log TFP is also 19% above South Korea's value of 2.38.

East Asia has the highest governance level, with an average of .535. This is followed by South-East Asia (.102), South America (.054), MCC (-.254) and Mexico (-.269). South Korea's governance level over the period is .327, which is low compared to Hong Kong (.636) and especially compared to that of Singapore (1.543), which is the highest among the 32 sample countries. The second highest level is that of Chile, which is equal to .981. El Salvador's governance level is, at -.904, the lowest in the 32-country sample.[15]

Table 1 shows that educational attainment (the percent of population aged 15 or above with high school degree) is highest in South Korea (49.5) and East Asia (45.8), followed by South America (26.2), Mexico (24.3), the MCC region (23.9) and South-East Asia (19.8). The value for LAC is 25.2 and for Asia (i.e., the sum of East and South-East Asia) is 23.7, the latter's low value due mainly to Indonesia's low education and large population. The educational attainment gap between East Asia and LAC is 19.6 percentage points.

[15] This is essentially due to the very high level of violence over the period.

4.3. Growth in Income and NRD, and Increase in Education and Governance

Table 2 shows that per capita annual GDP growth over the period is highest in East Asia (4.8%) and is over twice that of MCC, over 2.5 times that of South-East Asia and eight times that of South America. East Asia's NRD growth rate is also the highest – with MCC close behind – and is close to twice that of South America and over three times that of South-East Asia.

Table 2 also shows that the increase in educational attainment between 1976 and 2007, in percentage points, was 43.9 for East Asia, 28.0 for MCC, 25.1 for South America and 19.9 for South-East Asia (and, which are not shown, 26.4 for LAC and 48.8 for South Korea), with East Asia's increase larger by 15.9, 18.8 and 17.5 than in MCC, South America and LAC, respectively. The increase in governance is largest for South-East Asia (.7) and South America (.6), and is about twice that for East Asia (.3) and MCC (.3).

4.4. R&D Stocks

Table 3 shows average R&D stocks and their growth rate for the G7 countries. The average US R&D stock is slightly larger than the sum of R&D stocks of the other six G7 countries, while the growth rate of US stocks is lower than that of the other G7 countries except for the UK. Its growth rate is 3.5% for the US, 5.4% for the rest of the G7 and is highest for Japan at 7.7%.

5. Empirical Results

Table 4 shows the estimation results of the benchmark equation (column 1), which uses the standard definition of NRD (in equation 1), with interaction terms in Columns 2 and 3. Column 1 shows a positive impact on TFP, of log NRD, education and governance, with coefficients equal to, respectively, .325, .022 and .587, all significant at the 1% level, where the first coefficient is an elasticity and the latter two are a semi-elasticity. Interactions of NRD with education, governance (not shown), and both education and governance are not significant, and education and governance become non-significant when interaction terms are included. Thus, our preferred regression in the linear model is column 1.

Table 5 is based on the non-linear measure of NRD from equation (2) and shows the following:

i) The coefficient of log NRD in the pooled regression (column 1) – which includes a dummy variable for R&D-intensive industries – is .286, significant at the 1% level, and is about five times greater for the R&D-intensive than for the low-R&D industry. Thus, a one percent increase in all imports or a one percent growth in all trading countries' R&D stocks has a much larger impact on TFP's level and growth in R&D-intensive than in low-R&D industry – implying, not surprisingly, a greater dependence of productivity on foreign knowledge in the industry that uses it intensively.

ii) The education coefficient in the pooled regression (column 1) is .0221 and is significant at the 0.1% level. As expected, it is larger for the R&D-intensive industry (significant at the 5% level) than for the low-R&D industry (not significant) since education is an essential input in R&D-intensive industries and is strongly complementary with knowledge (R&D). Note that its significance level is substantially greater in the pooled than in the R&D-intensive regression.

iii) The coefficient for governance is .536, significant at the 1% level, and larger for the low-R&D industry than for the R&D-intensive industry (which is not significant).[16]

iv) The coefficient of distance in the pooled regression is .762, significant at the 1% level, which implies a negative impact of distance on TFP (see equation 2). The impact is significant for the pooled regression, and for the R&D-intensive but not for the low-R&D industry. Since the share of transport in total costs is typically higher for low-R&D than for R&D-intensive goods, the result suggests that the bulk of the negative impact of distance in the R&D-intensive industry is due to the decrease in the TFP impact of foreign technology as distance increases rather than to the fact that the volume of trade falls with distance.

6. Robustness and Nested Equations

Before turning to the simulations, we perform tests to select equation (1) or (2) as our preferred regression. We test for the robustness of the results of equation (2) and for its goodness-of-fit

[16] This result may be due at least in part to the fact that R&D-intensive goods – such as equipment and machinery – tend to be manufactured by larger firms, while smaller firms tend to be more concentrated in the low-R&D industry, with the former having more influence on the authorities and the latter more dependent on good governance. Moreover, R&D-intensive goods tend to benefit from less restrictive and arbitrary trade regimes because the central role they play in the functioning of the economy is likely to raise the political cost of reducing their effectiveness.

relative to equation (1) and relative to equation (1'). The latter two tests are based on the fact that equations (1) and (1') are nested in equation (2).

For robustness, we used a 5% as well as a 15% R&D stock depreciation rate instead of the 10% rate in equation (2) for the pooled regression, with a negligible impact on the results. Second, we performed a formal F-test to determine whether including the distance variable (equation (2)) improves results in a statistically significant way relative to equation (1). The F-test value was compared to the value, F^*, in the F-distribution table, with $F > F^*$. [17] Thus, the hypothesis that equation (2) is the preferred one cannot be rejected. Third, equation (1') used by Keller (2002) is similar to equation (2) except for the absence of the trade variable, i.e., equation (1') is also nested in equation (2). We estimated Keller's equation and conducted the same F-test and found that the hypothesis that equation (2) is the preferred one cannot be rejected in this case either.

Moreover, the pooled regression has the best fit and its coefficients are all highly significant (at the 0.1% level), while at least one of them is not significant in the R&D-intensive and low-R&D industry regressions. And when education is significant, it is less significant than in the pooled regression. Hence, the latter is used in the simulations.

7. Simulation

This section examines what the level and growth of TFP would have been in LAC (and in South America, Mexico, and MCC) if governance, education or openness had been identical to those in East Asia, in Asia (i.e., East plus South-East Asia), or in South Korea. It also examines the TFP cost for South America associated with its greater distance from the G7 relative to MCC or Mexico, and similarly for Singapore relative to South Korea. Based on analysis in Section 6, estimation results from Table 5 (equation (2)) are chosen for the simulations. The results are presented in Table 7. All values are averages over the sample period (weighted averages for

[17] The test is as follows. The value for the F-statistic is $F = \frac{(SSR_1 - SSR_2)/k}{SSR_2/v}$, where SSR_1 (SSR_2) is the sum of squared residuals for equation 1 (2), $v = n - (k + p + 1)$, n is the number of observations, and k ($k + p$) is the number of variables in equation 1 (2). Selecting a level of significance α, the value of F is compared to that of $F^*(\alpha, p, v)$. The hypothesis being tested is H_0: $\delta = 0$, which is rejected in this case as $F > F^*$ at significance level 0.001. Thus, the hypothesis that equation (2) is the preferred equation cannot be rejected.

regions). The values for Log TFP, governance and education for the various regions are provided in Table 1.

7.1. Governance

The value of the governance coefficient is .532, with a one-unit increase in governance raising TFP by 53.2%. Average governance is .318 for (East plus South-East) Asia and -.121 for LAC, with a gap of .439. LAC's TFP is 7.46 or 70.4% of Asia's TFP of 10.60. Raising LAC's governance to Asia's level raises its TFP by .532*.439 = .234 or 23.4%, i.e., by 1.75, from 7.46 to 9.21, thereby reducing LAC's TFP gap with Asia by 55.7% (1.75/3.14). The same logic applies to the other simulations.

As Table 1 shows, East Asia's TFP is over twice that of LAC and its sub-regions. East Asia's (LAC's) governance level is .535 (-.121), with a gap of .656, and raising LAC's governance to East Asia's level raises its TFP (reduced the TFP gap) by 34.9% (23.1%). Corresponding figures for raising governance to East Asia's level are: 25.6% (13.8%) for South America, and 44.7% (34.6%) for Mexico. The corresponding figures for raising governance to South Korea's level are 23.8% (53.2%) for LAC, 14.5% (26.8%) for South America, and 31.7% (99.5%) for Mexico.

Within LAC, raising Peru's governance of -.198 to Chile's level of .981 – which is the second highest level after Singapore among the 32 developing countries in our sample – raises its TFP by 62.8% and reduces its TFP gap with Chile by 94%.[18]

Estimation results in Table 5 suggest that the results are especially relevant for the low-R&D industry, where the impact of governance is about 20% greater than for the pooled regression.

7.2. Education

The coefficient for education is .0221, i.e., a one-percentage point increase in education raises TFP by 2.21%. LAC's average level of education over the period 1976-2004 is 23.3, while that of East Asia is 60.9, with a gap equal to 37.6. The increase in TFP (reduction in the TFP gap) from increasing education to East Asia's level is 37.6*2.21% = 83.1% (55.0%) for LAC, with corresponding figures of 81.3% (43.7%) for South America and 85.6% (66.2%) for Mexico.

[18] The corresponding figures for raising Indonesia's governance to Malaysia's level are 50.7% (28.8%).

The corresponding figures for raising education to South Korea's level of 35.4 are 94.0% (131.1%) for LAC, 95.5% (100.0%) for South America, and 92.2% (150.7%) for Mexico. The impact is larger in this case than with East Asia, first, because South Korea's education level is higher and second, because its TFP is substantially lower than East Asia's and thus so is its TFP gap with LAC.

Results in Table 5 suggest that the simulation results are especially relevant for the R&D-intensive industry.

7.3. <u>Trade</u>

TFP's elasticity with respect to NRD is .285, which is close to the .29 value obtained by Coe and Helpman (1995) in the regression that includes total imports over GDP. Raising South America's import-to-GDP ratio to South Korea's level raises its TFP and TFP growth (reduces its TFP gap) by 22.0% (37.8%), with corresponding figures equal to 29.2% (90.4%) for Mexico, and 27.5% (59.6%) for LAC. For raising openness in LAC regions to East Asia's level, the corresponding figures are 50.1% (26.7%) for South America, 42.8% (33.1%) for Mexico, and 47.5% (31.4%) for LAC.

7.4. <u>Impact of Trade, Education and Governance</u>

This section provides figures for the sum of the impacts of raising education, governance and trade. An increase to East Asia's level raises TFP in South America (LAC) (Mexico) by some 157% (165%) (173%), and raises it by 84% (104%) (134%) of their TFP gap. Thus, it less than (approximately) (more than) eliminates the TFP gap with East Asia. In other words, raising LAC's education, governance and trade to East Asia's levels is expected to approximately close the productivity gap with it. And with South Korea's TFP being 40% below that of East Asia, raising education, governance and trade to South Korea's level should have a bigger impact in terms of closing the productivity gap for South America (Mexico) (LAC) with it, as shown in Table 6.

7.5. <u>Distance</u>

This section examines the impact on a developing country's TFP of being farther from a G7 country. The difference between $D_{c_1k_1}$ and $D_{c_2k_1}$, the distance from country c_1 or c_2 to G7 country k_1, is denoted by $d(Dist)$. From equations (2) and (3), the impact on TFP of $d(Dist)$ is $dlog(TFP) = -\beta\delta e^{-\delta * Dist} d(Dist)$. With $\beta = .285$ and $\delta = .76$, $\beta\delta = .217$, and thus $dlog(TFP) = -.217 e^{-.76 * Dist} d(Dist)$.

We examine the impact on South America's TFP relative to Mexico or MCC of being more distant from "US + Canada" (USC), from Japan, from the four European G7 countries (France, Germany, Italy and the UK) and from the G7 as a whole. We also do the same for South Korea relative to Singapore. The distance from South America (MCC) to USC is 6.075 (3.040) thousands of km, with the difference between the two equal to: $d(Dist) = 3.035$, and with $-e^{-\delta * Dist} = -e^{-.76*3.04} = -e^{-2.31} = -.1$. Hence, the impact on South America's TFP and TFP growth relative to that of MCC is equal to –.217*.1*3.04 = – 6.6%. Mexico's distance to USC is 2.712 and the difference with South America is 3.363, with $-e^{-\delta * Dist} = -e^{-.76*2.712} = -e^{-2.06} = -.127$, and the impact on South America's TFP and on TFP growth relative to that of Mexico for imports from USC is – .217*.127*3.363 = 9.3%, while it is about nil in the case of distance to Japan and to Europe.

With distance from South America (Mexico) to Japan of 16.540 (11.324), the impact on the TFP of South America relative to that of Mexico is –.02% ($-e^{-.76*11.324} = -.00018$, and $-.217*.00018*5.216 = -.0002$), and similarly for South America's TFP relative to MCC. The same results obtain for distance to Europe. Hence, given the share of USC in South America's imports relative to those from the G7 as a whole, the overall loss for South America due to its greater distance to the G7 relative to MCC (Mexico) is about 3.0% (4.2%).

As shown in footnote 20, the loss of TFP for Singapore relative to South Korea is 37.5% for imports from Japan, close to nil for imports from USC and from Europe, and 15.4% for imports from the G7.[19]

[19] The distance from Singapore (South Korea) to Japan is 5.310 (1.155), with an impact on Singapore's TFP relative to South Korea's TFP of -37.5% due to the fact that its distance to Japan is over 4.5 times that of South Korea. On the other hand, the impact on Singapore's TFP relative to South Korea's of its greater distance to USC is –.03%, and similarly for the TFP impact of the difference in distance to Europe. Hence, the overall loss in Singapore's to South Korea's TFP from the former's greater distance to the G7 countries is obtained as -37.5% multiplied by the share of Japan relative to the share of the G7 in Singapore's imports, whose average over the period is .176/.427 = .411, i.e., the overall loss is 15.4%.

9. Conclusion

High levels of economic growth require commensurate levels of productivity growth to be sustainable over time. This paper examined the impact on total factor productivity (TFP) in the South of education, governance, trade – the latter working through its impact on North-South technology diffusion – and distance from the North. The analysis focused on East Asia and LAC and simulated for the period 1976-2007 the impact on TFP in LAC (and in its sub-regions) of raising the level of TFP's determinants to their level in East Asia or South Korea.

The main findings are:

i) TFP rises with openness to trade, education, governance and imports' R&D content, and falls with distance;

ii) An increase in trade, governance and education to the East Asia level raises TFP in LAC by well over 100 percent and closes its TFP gap with East Asia. Similar results obtain for South America and Mexico.

iii) The impact on TFP and on reduction in the TFP gap is largest for education, trade's impact is second and that of governance is third. The impact of raising education to the level of East Asia (South Korea) is equal to (greater than) the sum of the impacts of trade and governance; and

iv) The TFP loss for South America relative to Mexico due to its greater distance to 'US plus Canada' (Japan) is about 9 percent (negligible). Similarly, the TFP loss for Singapore relative to Korea due to its greater distance to Japan ('US + Canada') is over 30 percent (negligible).

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Table 1: 1976-2007 Mean of Key Variables by Region [a]
(Weighted Average)

Region	Log TFP [b]	Governance	Educational Attainment [c]
East Asia	2.93	.535	45.8
South Korea	2.38	.327	49.5
South-East Asia	1.80	.102	19.8
Asia [d]	2.36	.318	23.7
South America	1.88	.054	26.2
MCC	2.15	-.254	23.9
Mexico	2.10	-.269	24.3
South America + Mexico	2.00	-.122	25.4
LAC	2.01	-.121	25.2

a: The variables are defined in Section 3;
b: Average is weighted by GDP;
c: Average is weighted by population;
d: Asia is defined here as the sum of East Asia and South-East Asia.

Table 2: Annual Growth Rate (%) and Increase, 1976-2007*

Region	Growth (per cap. GDP)	NRD Growth	Education Increase	Governance Increase
East Asia	4.8	6.8	43.9	.3
South-East Asia	1.8	2.1	19.9	.7
South America	.6	3.5	25.1	.6
MCC	2.2	6.4	28.0	.3

*GDP growth is the annual growth rate of per capita GDP (in PPP); NRD growth is an annual growth rate; Education increase is a percentage point increase of quality-adjusted education during 1976 – 2007, and Governance increase is the change in the value of the variable in 1976 - 2007.

Table 3: Mean R&D Stock Levels and Growth, G7 Countries, 1976-2007

Country	Mean (billion US dollars)	Growth rate (%)
Canada	20.5	7.1
Germany	176.8	5.9
France	92.9	4.2
UK	88.8	2.2
Italy	38.0	5.3
Japan	275.4	7.7
USA	724.6	3.5

Table 4: Equation 1 – Linear Trade-weighted R&D Stocks (Dependent Variable: log TFP), 1976-2007 [a b]

Variable	(1)	(2)	(3)
Log(NRD)	.325***	.0576***	.0378
	(8.84)	(2.79)	(1.13)
Edu	.0219***	.0228***	-.0068
	(3.54)	(3.46)	(-.18)
Log(NRD)*Edu	___	___	.0017
			(.77)
Gov.	.587***	.218	.342
	(6.30)	(.022)	(.43)
Log(NRD)*Gov.	___	.163	.0105
		(.054)	(.35)
Year dummy	Yes	Yes	Yes
Country dummy	Yes	Yes	Yes
$adj-R^2$	0.661	0.657	0.655
Obs.	1750	1750	1750

a: Column 1 includes a dummy variable for R&D-intensive industries and all regressions include a constant; *b*: *t* statistics in parentheses; significance level: * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 5: Equation 2 – Non-Linear Trade- and Distance-Weighted R&D Stocks, 1976-2007 (Dependent Variable: log TFP) [a, b, c]

	All	Low-R&D Industry		High-R&D Industry	
	(1)	(2)	(3)	(4)	(5)
β	.286***	.112***	.100***	.544***	.545***
	(9.18)	(4.91)	(4.19)	(8.86)	(9.32)
δ	.762***	-.225	-.262	4.32***	4.33***
	(13.74)	(-0.72)	(-0.68)	(21.60)	(22.70)
β^{gov}	.536***	.664***	___	.153	___
	(6.47)	(7.16)		(1.21)	
β^{edu}	.0221***	.0102	.0192*	.0215*	.0215*
	(3.32)	(1.30)	(2.48)	(2.29)	(2.30)
Year dummy	Yes	Yes	Yes	Yes	Yes
Country dummy	Yes	Yes	Yes	Yes	Yes
$adj-R^2$	.905	.923	.924	.911	.911
N	1750	872	872	871	871

a: The pooled regression (Column 1) includes a dummy variable for the R&D-intensive industry, and all regressions include a constant;
b: High (Low) R&D Industry denotes the group of R&D-Intensive (Non-Intensive) Industries.
c: *t* statistics in parentheses; significance level: * $p < .05$, ** $p < .01$, *** $p < .001$.

TABLE 6: Simulation of Impact of Change in Governance, Education and Trade from LAC to East Asian Values, and of Change in Distance

Variable	Regions	Increase in TFP (%)	Reduction in TFP Gap (%)
1.Governance	LAC vs. East Asia	34.9	23.1
	S. America vs. East Asia	25.6	13.8
	Mexico vs. East Asia	46.1	34.6
	LAC vs. South Korea	23.8	32.5
	S. America vs. South Korea	14.5	15.2
	Mexico vs. South Korea	35.0	55.8
2. Education	LAC vs. East Asia	83.0	55.0
	S. America vs. East Asia	81.3	43.7
	Mexico vs. East Asia	85.0	66.2
	LAC vs. South Korea	94.0	131.1
	S. America vs. South Korea	92.3	100.0
	Mexico vs. South Korea	96.0	150.7
3. Trade	LAC vs. East Asia	47.5	31.4
	South America vs. East Asia	50.1	26.7
	Mexico vs. East Asia	43.4	34.4
	LAC vs. South Korea	27.5	38.3
	S. America vs. S. Korea	30.1	23.0
	Mexico vs. South Korea	23.4	40.1
Sum of Gov., Educ., Trade	LAC vs. East Asia	165.4	104.4
	S. America vs. East Asia	157.0	84.2
	Mexico vs. East Asia	173.1	133.9

	LAC vs. South Korea	145.3	201.9
	S. America vs. S. Korea	132.0	128.2
	Mexico vs. S. Korea	154.4	246.5
4. Distance (impact in %)	S. Amer.-USC[1] vs. MCC[2]-US	- 6.6	
	S. Amer.-USC vs. Mex.-USC	- 9.3	
	S. Am.-Japan vs. MCC-Japan	- 0.02	
	S. Am.-Japan vs. Mex.-Japan	- 0.02	
	Singapore-Japan vs. South Korea-Japan	-37.5	
	Singapore-USC vs. South Korea-USC	-0.03	

1. USC refers to US and Canada.
2. MCC refers to Mexico, Central America and Caribbean.